Total Ship System Engineering

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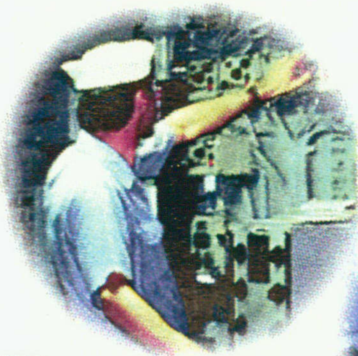

Combat Systems Department

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NAVAL SEA SYSTEMS COMMAND
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Total Ship
System Engineering

A GANG OF SIX INITIATIVE

OCTOBER 1996

COMBAT SYSTEMS DEPARTMENT
NAVAL SURFACE WARFARE CENTER DAHLGREN DIVISION
DAHLGREN, VIRGINIA

TASK AND DRIVERS

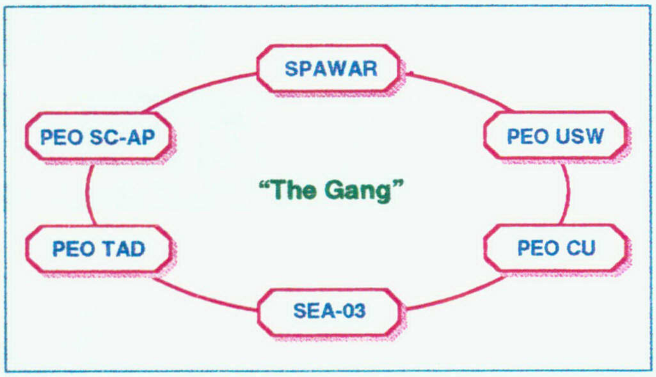
Reinventing the process by which military needs are transformed into combatants and warfighting systems is a task of great moment for the Navy. This report considers a reinvention effort driven by three factors:

- *Making sure the design process is driven by what the warfighters (mission teams) must do - that is, put ordnance on target;*
- *Adopting a "system of systems" approach to integration so that a unity of effort can be maintained across all parts of the ship, from keel to masthead;*
- *Making sure that capable ships are also affordable through continual improvement of acquisition practices.*

These drivers, together with the leadership necessary to build a culture of teamwork, constitute the elements of a framework for reinvention.

In this section of the report we outline the total ship system engineering framework and the status of efforts to reduce it to practice. The next section reviews the traditional approach to total ship engineering, its origin and evolution, and the underlying concept of organization. The third section considers implications of the new framework for ship design and engineering activities, while the last section envisions how ship characteristics may be changed.

THREE FACTORS



CHAMPIONS

"The Gang"

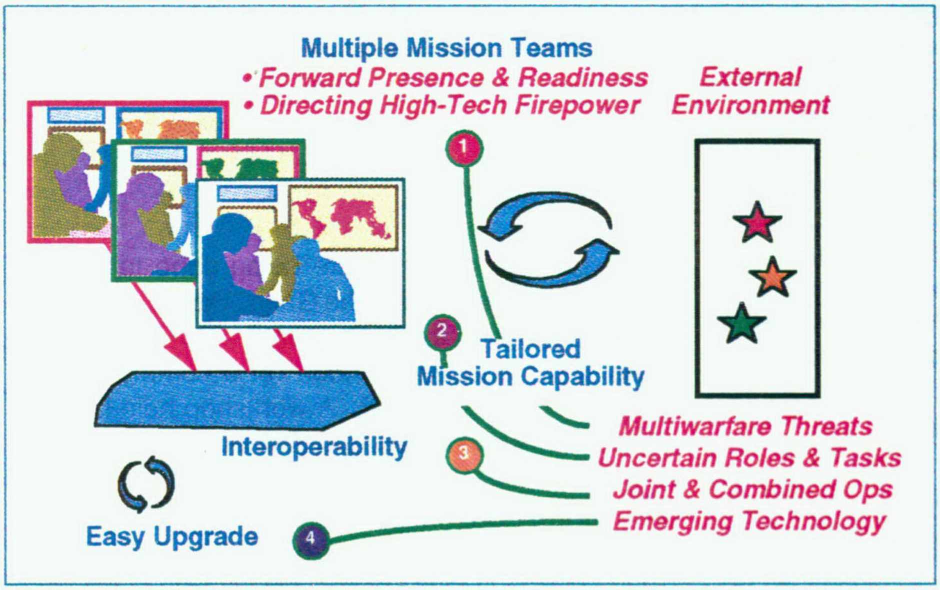
A group of key Navy acquisition executives served as champions for this effort. The activities shown in the figure were the main contributors, but others took part at times. This group, often called the "Gang of Six," provided strong support to the idea of building a culture of teamwork that overcomes the stovepiping tendencies of the past.

Several related efforts must also be acknowledged. Substantial help was provided by the RDT&E Division (NRaD) of the Naval Command, Control, Communications and Ocean Surveillance Center. The Training Systems Division of the Naval Air Warfare Center, the Naval Postgraduate School, and other divisions of the Naval Surface Warfare Center (NSWC) have also participated in the effort.

What Mission Teams Must Do

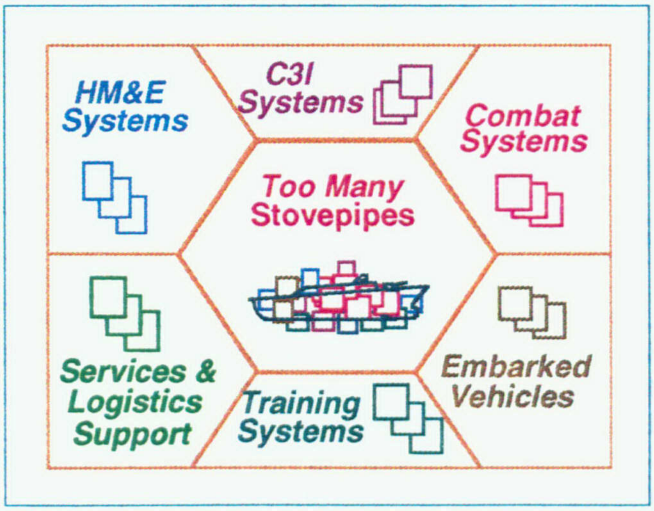
We can think of ships in terms of the mission teams that they carry to the operating area, where the teams may be called upon to maintain presence or to deliver high-tech firepower against an adversary. No purpose is more important in total ship system engineering than to build ships that can provide what the warfighters need.

To support multiple mission teams in forward operating areas, ships must be very flexible, capable of tailoring basic capabilities to the designated mission tasks and operating environments. Teams will have to deal with multiwarfare threats, in heavy clutter. Uncertainty about roles and missions is characteristic of regional conflict situations, and the rules of engagement are often complex. Navy and Marine Corps mission teams will operate as integral



SUPPORTING MISSION TEAMS

parts of joint and combined forces. (Because stovepiping concerns increase with the level of force integration, this alone warrants an effort to reinvent the process by which requirements are transformed into ships.) Due to the pace of technological progress, the ongoing "revolution in military affairs," and the importance of open systems for affordability, ease of upgrade must also be emphasized.

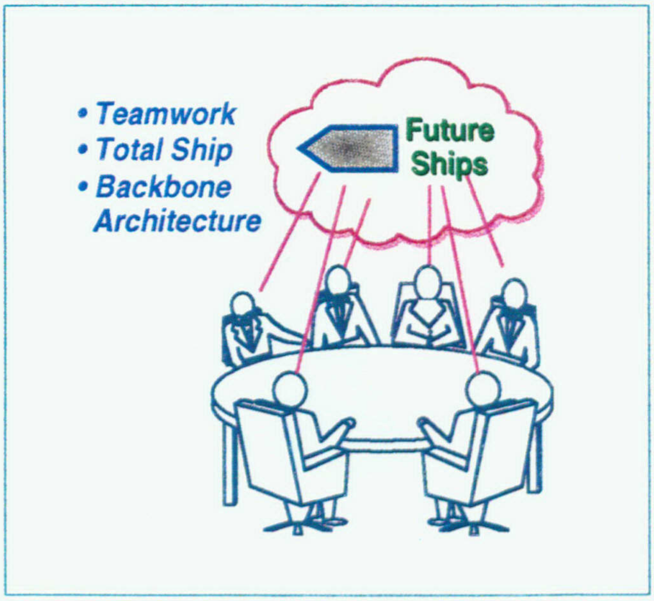


ACQUISITION STOVEPIPES

"System of Systems"

The Navy is faced with a number of challenges to its total ship system engineering capability. As the figure suggests, a ship is a composite of many individual systems, each developed with minimal coordination. In the existing acquisition culture, systems (a) tend to mirror how we are organized, (b) are developed with many unique components, and (c) are procured as commodities for integration into larger systems. Under such conditions, creation of well-integrated ships demands a major integration effort. We have been able to make some progress by working hard to overcome the barriers. But success remains elusive, and the downsizing now in progress threatens our ability to execute this approach in the future.

The alternative is to build systems that work together by design, so that the ship as a whole becomes a "system of systems." This can be achieved by creating, between the ship level and that of individual systems, some kind of framework for teamwork in development of the individual systems. The top-level partitioning of control functions for the ship is seen as a key factor. The core problem is not how to break a ship into individual systems, but how the

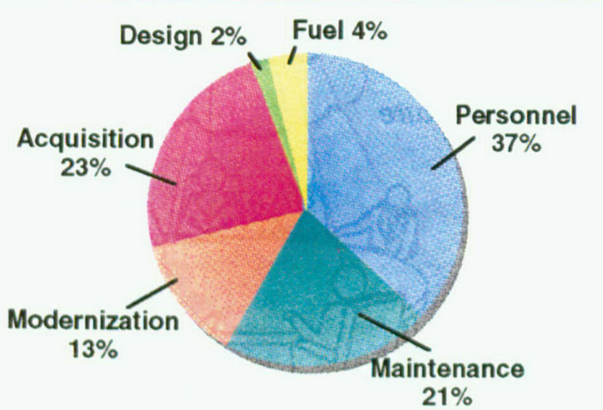


SYSTEM OF SYSTEMS

systems can be made to work together as parts of a unified whole (total ship). Our approach to partitioning, outlined on page 7, creates three backbone elements (combat control, plant control, and information management) to foster integration. The first two involve some change in the traditional partitioning of combat systems from hull, mechanical, and electrical systems. The last recognizes that information is a resource demanding coordination on a shipwide basis and that special attention may be needed to create the necessary means for coordination.

Acquisition Process Improvement

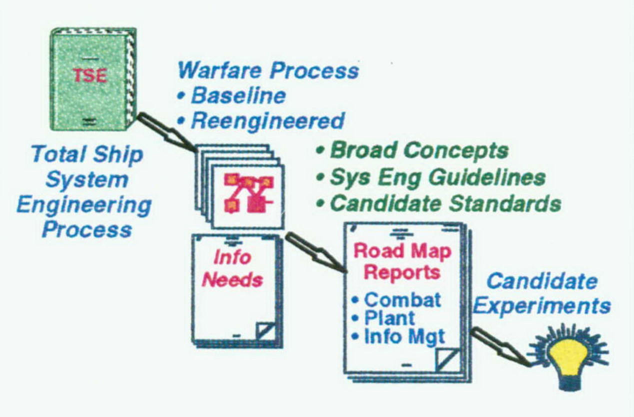
The third major element of the reinvention strategy has been to foster a disciplined system engineering approach in which affordability and capability are considered as two sides of the same coin (i.e., a strong fleet). The aim is to achieve major gains in affordability without sacrificing needed capability. This can be done by reinventing the total ship system engineering enterprise to improve productivity across the board. The pie chart from Reference 1 shown here applies to life cycle cost for a typical naval ship. The relative size of the pieces will differ for any particular design. The largest piece shown, personnel cost, can be addressed by automation and by process reengineering. While the original data applies to the ship's crew, ashore personnel costs must also be recognized as a contributor. Other areas can be addressed by exploiting commercial products and by reinventing development and support processes. There is also potential for broad gains through improved productivity in shipbuilding and construction.



LIFE CYCLE COSTS

What We Are Doing

A number of things are being done to pursue the goals articulated by "the Gang." Reference 2 lays foundations for a total ship system engineering process and highlights the idea of a common backbone for combat control. A workshop held last fall made useful contributions to definition of the remaining backbone elements, in plant control and readiness and in information management; Reference 3 gives results. The workshop addressed reengineering ideas for selected mission teams and tasks. Reference 4 expands on the backbone concept featured in the earlier reports.



EXPLORING THE CONCEPT

While several reports have been written, the main value of the effort is not in reports but in drawing different parts of the surface ship community into a dialog on total ship system engineering practices. A process for coordinated efforts to identify agreed-to design concepts or target architectures, standards, and engineering tools would mean a big step forward. Consensus guidelines could be used by major programs to ensure their products fit into the target ship design and can be used in other classes as well.

TRADITIONAL SHIP ENGINEERING PROCESS

History

As the figure below suggests, the Navy has experimented with many different approaches to ship design. Stovepiping and the increasing complexity of modern systems have been constant concerns throughout this period. In the 1950s, design functions were largely performed in house. The Bureau of Ships (BuShips) had separate organizations for preliminary design and contract design. There was some in-house construction at naval shipyards. In the 1960s, the concept of total package procurement shifted design of several major ship classes to the private sector. Use of public shipyards for new construction was eliminated.

- **Defense Acquisition Reform (CHENG D/A/C Project) - 90s**
- **Ship Procurement Process Study (Competition) - 80s**
- **Design to Cost - 70s**
- **Total Package Procurement - 60s**
- **BuShips Reorganization - 50s**

THEMES SINCE 1950

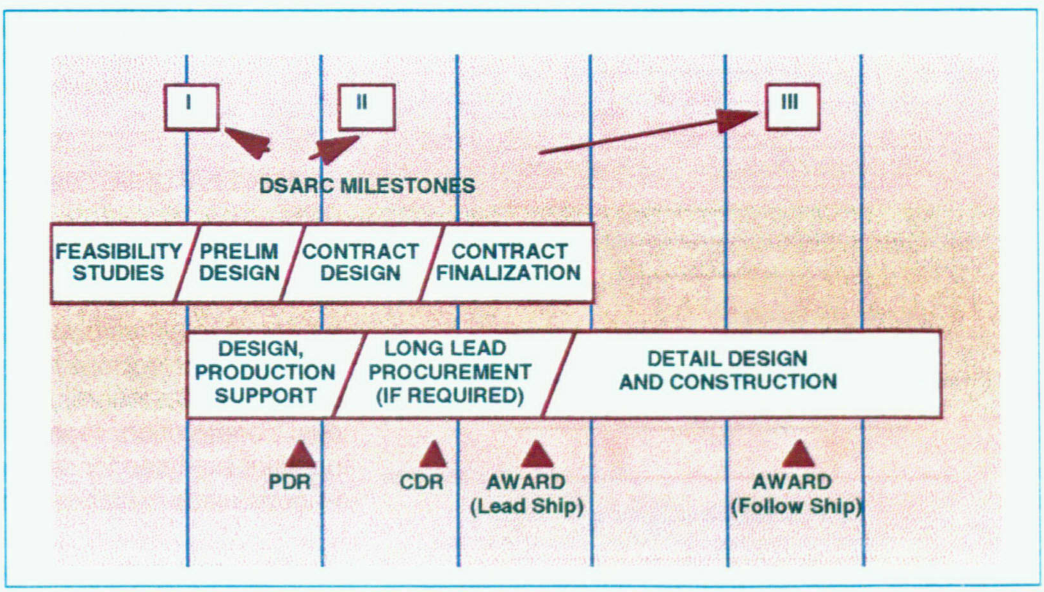
In the 1970s, there was a return to in-house ship design with a central design management organization in the Naval Ship Engineering Center (NAVSEC). However, the design-to-cost philosophy was practiced for much of the decade. The growing Soviet naval threat became a dominant theme in the mid-1970s, causing a great deal of attention to be paid to concepts and methods of ship design and engineering.

Acquisition streamlining became a major theme in the 1980s, with increased shipbuilder participation in the design process. This trend has continued into the present, with Defense Acquisition Reform and commercialization emerging as major themes.

Baseline Process

The sequence of events shown applies in a general way to naval ship design since 1970. For many years, the overall strategy for ship design, construction, and support has been dominated by a bottom-up approach to design and development. Ship designers choose the hull form and propulsion machinery for desired maneuvering and seakeeping qualities, while ship size and arrangement are varied to meet demands for space, weight, aperture, and stability driven by the required payload systems. The basic concept is to deal with problem complexity by dividing component development responsibilities among a loosely coordinated array of programs. Each program office builds a little, tests a little, specifies, and finally produces a stand-alone system.

The ship is then constructed by a process of component assembly and integration, proceeding



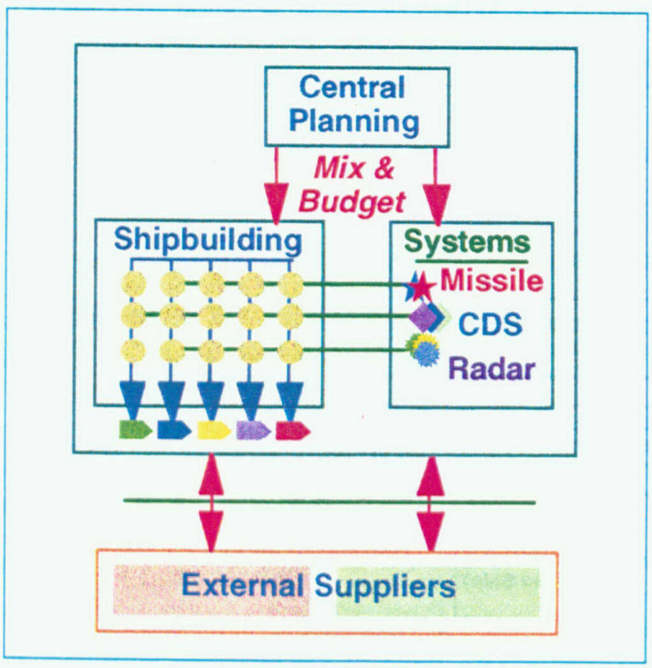
BASELINE ACQUISITION PROCESS

from the keel up. Ship designers have traditionally acted as physical integration agents, defining the hull, mechanical, and electrical interfaces necessary to package the stand-alone systems into the hull. In this context total ship engineering means ensuring that appropriate ship elements are selected and effectively and efficiently combined to satisfy operational requirements and design constraints.

While this approach yields warships that work, it is costly in terms of acquisition, manning, and logistics support and has made it difficult to achieve a highly integrated control structure. Today computing capacity is virtually unlimited, freeing the designer to engineer the ship as a system of systems. Qualities of firepower, stealth, interoperability, and affordability needed in future warships make a top-down, integrated design process imperative.

Underlying Concept Of Ship Development

Despite the many twists and turns in acquisition policy, the core process shown below seems to have been fairly stable over time. To begin, the strategy is one of centralized planning and decentralized execution. The Office of the Chief of Naval Operations (OPNAV) plans the force and the Naval Sea Systems Command (NAVSEA) executes the programs.



CORE PROCESS

Ships are designed by a central engineering staff, with detailed design and construction contracted to a shipyard.

The core process resembles the "command and control" scheme pioneered by General Motors to produce a car for "every purse and purpose." Many ship types are produced, each with different mission-critical systems but many common components as well. Where possible, common designs may be used across the entire Fleet. A typical ship has scores of individual systems, each with a specific purpose, and thousands of functionally complete components. Scores of acquisition programs and thousands of suppliers are involved in creating components and delivering them to the shipyard. In the reference process, the central engineering staff designs the parts and gives the drawings to suppliers for bid. Some of the suppliers are in-house activities, and bureaucracy is a factor in dealing with them. Price is the main factor in dealing with external suppliers, and the process is vulnerable to buy-in.

Centralized Planning & Decentralized Execution

In-House Team Leader
- ***Control Design Process***
- ***Collocated Design Team***
- ***Converging Programs***
- ***Built-in Stovepipe Effects***

Many External Suppliers
- ***Detail Design & Construction***
- ***Many Individual Systems***
- ***Integration After the Fact***
- ***Vulnerable to "Buy-in"***

MAIN FEATURES OF REFERENCE PROCESS

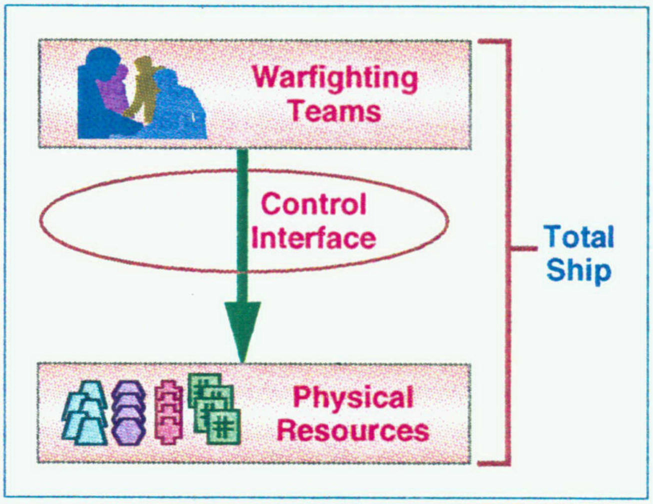
The reference process is intended for in-house execution, and where used by industry, roughly 30 percent of total value may be produced by outside suppliers. This includes bulk materials and commodities (such as fasteners) that are widely available. In naval construction, teams of internal and external suppliers are used for each system and ship, so the in-house value added is comparatively low.

The next section describes an alternate approach that can be pursued to achieve desired outcomes.

TOTAL SHIP SYSTEM ENGINEERING APPROACH

Point Of Departure

Regardless of the approach to spatial arrangement and physical modularity, a control structure is necessary to make the ship responsive to command direction and control. In defining a framework for dealing with command and control functions on a total ship basis, we start with a simple view of the ship as shown below.



SIMPLIFIED VIEW

People are shown at the top, organized into mission teams. Only by the direction of its crew does the ship become a complete warfighting system, capable of acting on its own to some degree. Even a fully automated ship would execute broad plans and orders only in accordance with direction from a mission team located elsewhere. The mission teams are supported by various categories of physical resources (radars, ship machinery, missiles, etc.), accessed via control interfaces. What is being addressed in the system of systems framework is the process by which the control interfaces are engineered. An expanded view appears in the next figure.

The strategy for partitioning control resources on a total ship basis is rooted in basic principles of system engineering. The first principle is that the aim of design must be to help the warfighters in achieving their operational objectives. The implication is that a partitioning for total ship design must be driven first and foremost by operational considerations. Another important principle is that engineering work units should be organized on the partitioning thus determined. The control structure thus reflects two key viewpoints. The first must be a warfighter's view, considering the essential military purpose of the ship. The second is that of the development organization responsible for ship design, acquisition, construction, and support.

Mission Operations

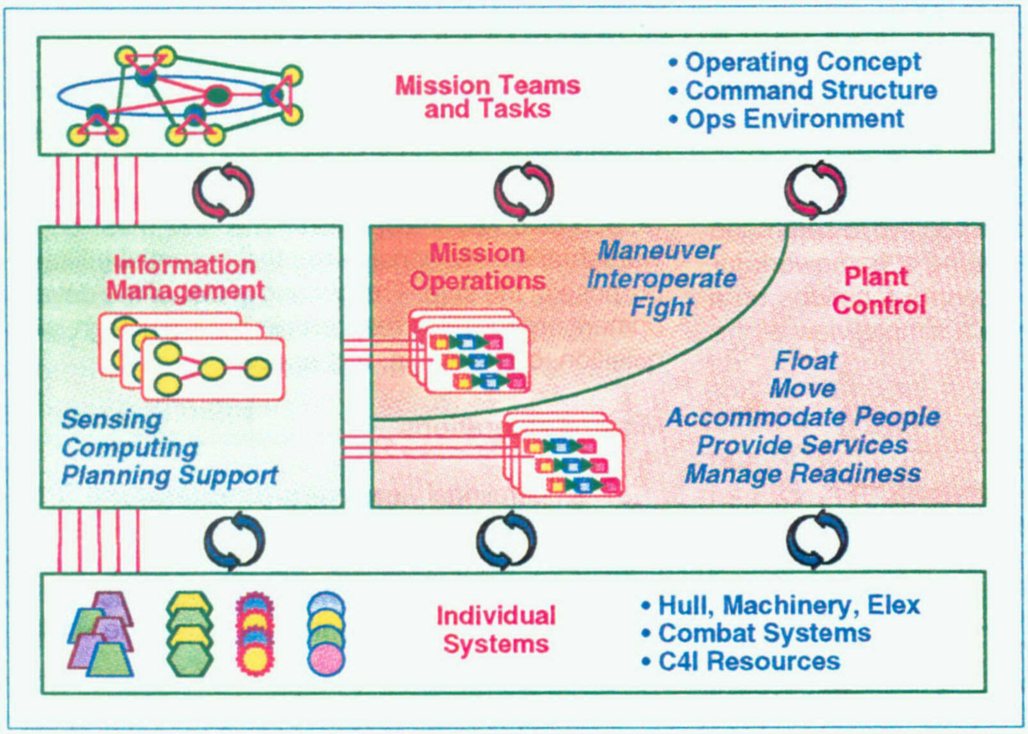
The operational viewpoint is considered first. The center section of the previous figure is here expanded a bit to show the basic structure of the control interface functions. How the control structure is partitioned, and how the parts interact, is the key to total ship integration.

Combat control (mission operations) and plant control involve a rearrangement of the traditional partitioning of combat systems from hull, mechanical, and electrical systems. However, in future ships the position of this boundary may change. Maneuver control and damage control coordination are areas that may move across the boundary. Information management, the third element of the partitioning, recognizes that information demands coordination on a shipwide basis and that special attention may be necessary to create suitable means of coordination.

The three major elements we refer to as control backbones. Some of the major functions to be controlled in each are shown in the figure. As a system of systems, the ship provides mission teams in each area with the resources to perform all assigned tasks, together with the interfaces and interconnections that make them responsive to human direction and control. For ships that are not combatants, the term Mission Operations can be used in place of Combat Control. With this convention, the partitioning shown is applicable to all ship types.

System of Systems

As indicated earlier, the missing factor in today's approach to total ship system engineering is a framework for dealing with the ship as a system of systems. What is lacking, in other words, is a way of

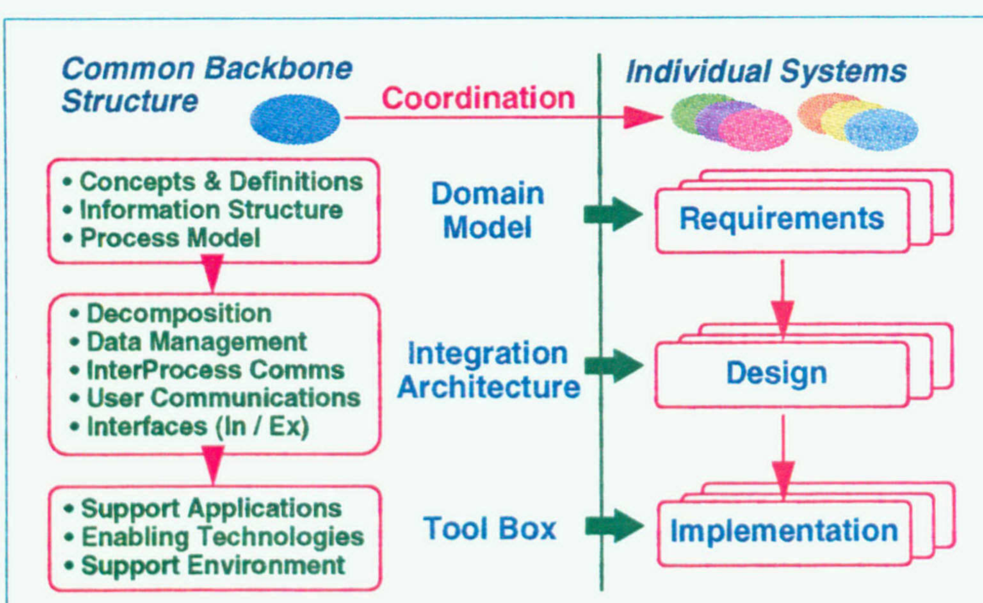


LAYERED CONCEPT FOR TOTAL SHIP "SYSTEM OF SYSTEMS"

defining and controlling the system engineering process across the entire set of independently designed and procured components to meet the requirements for a surface combatant. Some things this framework should strive for include (1) a fully integrated control structure, (2) ability to share system resources as necessary to coordinate and support subsystems, and (3) the ability to change and upgrade components easily.

For a large composite system such as a ship, dealing with component systems one by one is not good enough. A better approach is needed, one that permits coordination of many independent projects to create a fully integrated system of systems. Use of a generic framework, dividing the effort into several projects and two levels of management, is suggested. The following figure shows such a framework. One level provides coordination for the overall system, working across projects, while the other manages individual projects. Establishment of this framework begins with domain analysis, to establish a common foundation for specifying system concepts and requirements. Next, infrastructure and integration architecture are used to enable integration of component systems into a consistent overall system in an efficient way.

System of systems engineering involves two kinds of integration, one that focuses on mechanisms used to interconnect parts and another that focuses on the coherence of an overall system design. A dictionary definition of the term integration (make whole or complete by bringing together parts) succinctly captures this tension between the parts



TWO-LEVEL FRAMEWORK

and the whole. On the one hand, we talk about a system, a whole or complete thing; on the other, we talk about bringing together parts. The system side of the equation emphasizes global system properties, such as a harmonious "look and feel" in user interfaces, or the linguistic elegance of system structure. The parts side of the equation emphasizes interconnection and interoperation (e.g., of functions, data files, and subsystems).

Sequence of Design Decisions

The core of the system engineering problem is not how to decompose the overall system into subsystems but how to integrate subsystems into an overall solution. The challenge is to decompose tasks and to allocate subtasks without compromising the wholeness of the task. When the problem is viewed from this perspective, it is clear that a system engineering process involves a set of interacting or interdependent subproblems. The sequence for addressing the subproblems, together with the solution strategies employed, becomes a specification for the process.

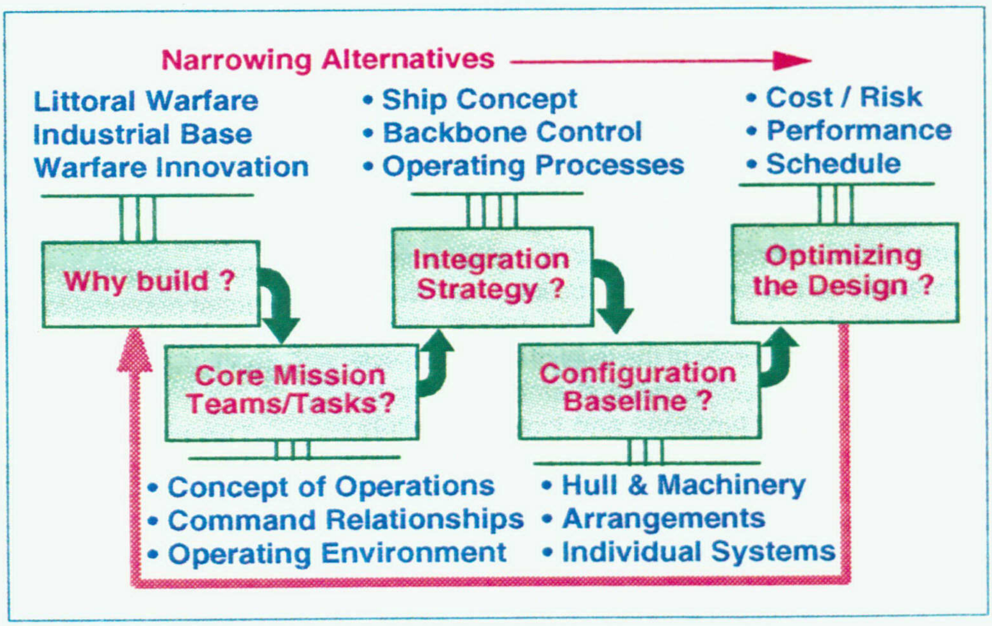
Although problem solving may follow a spiraling and iterative trajectory through the different sets of subproblems, the solution at any stage cannot be finalized until solutions are reasonably well worked out for previous stages.

Teamwork In Acquisition

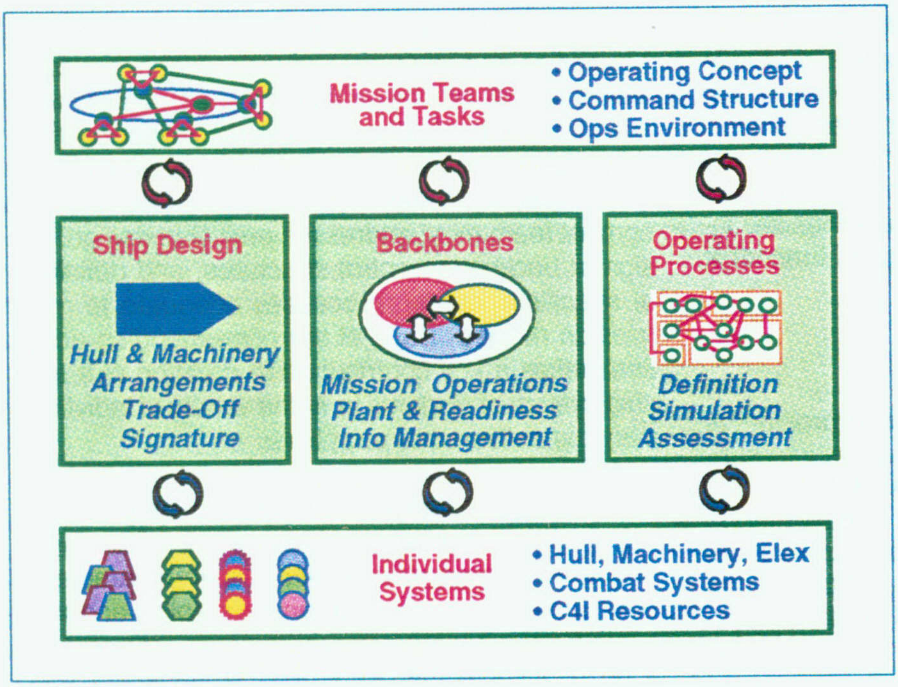
The development enterprise must be structured to maximize value delivered to mission teams on a life cycle basis. This drives the role of the development team leader, who must be concerned with the enterprise as a whole, working to shape the value stream to maximize value delivered. Core concerns of the lead activity are highlighted in the next figure, which represents a layered concept for organization of a total ship system engineering enterprise.

Because the development team must deal with acquisition and integration of individual systems as well as overall ship construction, its organization is a bit more complicated than the operational control structure. Once an adequate understanding of mission teams and tasks has been created, the development team must address overall ship design, design of backbone control structures, and definition of specific operating processes adequate to meet mission needs. Each of the corresponding activities makes a key contribution to creation of a total ship system of systems from the variety of individual systems delivered by suppliers.

The ship design activity provides the engineering studies necessary to address the questions of ship form, size, and essential military characteristics. Speed, seakeeping, strength, stability, and style are the major naval architecture issues. These characteristics are all interrelated and dependent on overall ship configuration and dimensions. Accordingly, this activity controls the ship design budgeting process, including signature and survivability, in addition to weight, space, moment, and cost factors. It also provides the physical interfaces (spatial, mechanical, and electrical) necessary for the many individual systems packaged into a multimission ship. Virtually all the resulting information finds its way



SEQUENCE OF DESIGN DECISIONS



ORGANIZING FOR TOTAL SHIP SYSTEM ENGINEERING

into the drawings and specifications used by the shipbuilder.

The backbone design activity provides for integration of all on-board control resources, in effect making the ship a real "system of systems." Ships are composed of many individual systems. The control structure must include mechanisms to facilitate cooperation among them, without compromising their ability to perform mission tasks. Just as domain models permit a common understanding of goals and requirements at the level of individual systems, the backbones permit a shared understanding of how control functions and interfaces will be handled. Their creation will establish a standard for services available to individual systems, and provide guidelines for the design of control structures and interfaces by individual projects.

An activity responsible for process evaluation and integration is also necessary. The basic purpose of this activity is to understand what mission teams must do and how well the ship, as a system of systems, can create and coordinate action paths adequate to meet operational needs. This calls for a total ship perspective together with a capability for detailed analysis of ship characteristics and performance.

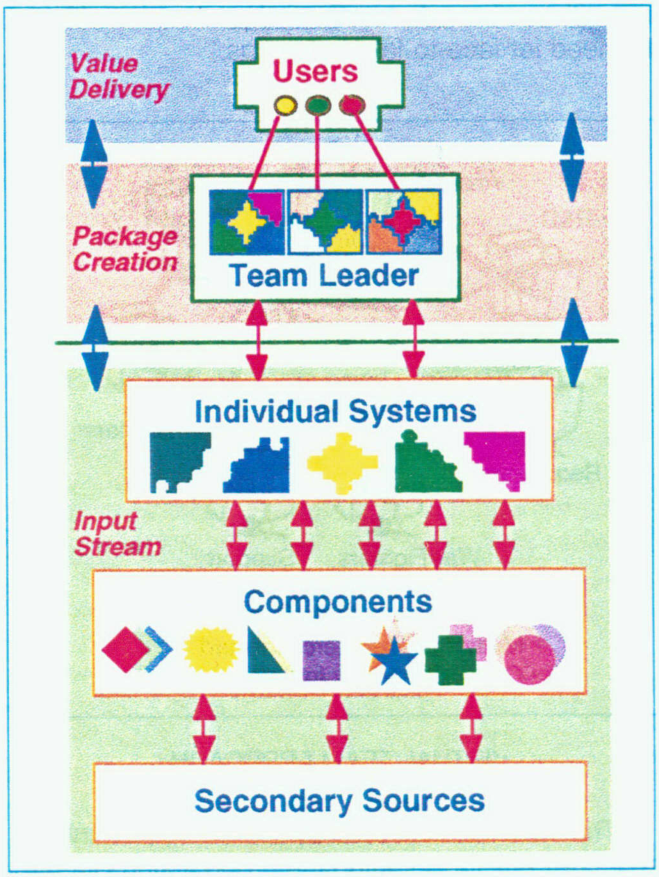
Seeking An Integrated Value Stream

The effort to reinvent surface combatants doesn't stop with a new emphasis on mission teams and the system of systems integration framework. The Navy can also reinvent how it organizes for design, construction, and support of future surface combatants. Current acquisition reform concepts, including the use of integrated product and process development methods, are based on this theme.

In fact, industry has turned reinventing the enterprise into something of a global trend. For the most successful efforts, thinking in terms of a value stream has been the first step. The enterprise is defined not as a single activity but a group of activities working together to supply a good or service in a way that creates maximum value for the customer (in our case the warfighter or mission teams). This drives the role of the enterprise leader, who must act to shape the overall value stream and not value added by direct individual effort alone. This causes a shift away from stovepipe thinking to global or team thinking. In particular, greater attention is given to relationships among team members, and to the transactions between them that often have the most potential for effectiveness and productivity gains. The figure indicates how such an enterprise might be structured.

This approach is widely viewed as an improved model for design of large productive systems. The original implementation is credited to Eiji Toyoda and Taiichi Ohno and is sometimes called the Toyota Production System.[5] The basic aim was to form a vast group of suppliers and parts plants into a single "machine" by producing at each step only those parts necessary to satisfy immediate demand at the next step. The final assembly organization functions as the enterprise leader. Usually, design and production of components that tend to define product style and performance (the product's *"signature"*) are performed in house. Thus the enterprise maintains control of the product line, but the value added by in-house divisions may be as little as 25 percent of the total.

Suppliers are organized into functional tiers, with multiple products and multiple sources in each tier. First-tier suppliers have an integral role in product development and are assigned a whole component to design. The suppliers work to a performance specification for a system that must work in harmony with other components, from other suppliers. Toyota formed first-tier companies by spinning off in-house divisions and building long-term alliances with external suppliers. Production is typically shared among several sources, with shares fluctuating up or down according to performance.



VALUE DELIVERY ENTERPRISE

Second-tier suppliers tend to specialize in a manufacturing process. A first-tier supplier might design an alternator, for example, and buy all parts from second-tier suppliers. The latter have no role in overall product design but may produce drawings for individual parts and have firms at still lower tiers produce parts to those drawings. Since companies at level 2 generally do not compete for specific component types, they can work together in supplier associations for the purpose of sharing information on manufacturing techniques.

The concept of operation is based on mutually agreed pricing, strong incentives for performance and sharing of information, and long-term relationships. Direct competition for production work between in-house and external activities is avoided, as it tends to be inefficient and unfair.

For surface ships, maximizing value delivered to mission teams on a life cycle basis would become the basis for organization. The enterprise leader is viewed as an integrated product team (IPT) with both Navy and builder elements. Core concerns of the leader are mission teams and tasks, overall ship design, backbone control structures, and definition of operational processes, as shown on Page 10. In short, the enterprise leader controls the overall design process, including weight, space, and cost budgets; the strategy for integration and control of mission capability; and creation of the mission-critical capabilities that are the reason for taking the ship to sea.

Beyond this, we believe the Navy should rethink the entire chain of supply, adopting the best practices from major enterprises around the world. At each tier, supplier associations can be formed to create open specifications and standards; process improvement techniques can also be shared. Suppliers in the first tier (major systems) should participate in overall ship design. Lower-tier suppliers

Establishing User Needs
- ***What Must Warfighters Do?***
- ***Role of Surface Ships***

Role of Team Leader
- ***Vision of Total Value Stream***
- ***Design & Budgeting Process***
- ***Integration Strategy***
- ***Mission-Critical Systems***

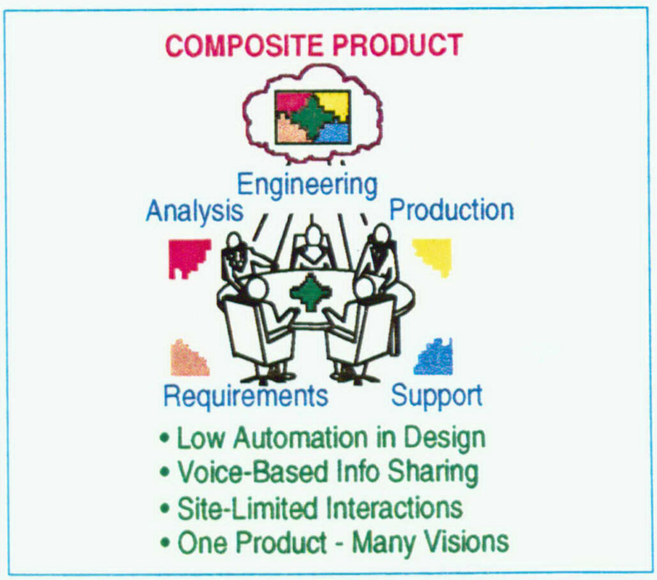
Rethink Chain of Supply
- ***Multiple Streams & Sources***
- ***Performance Incentives***
- ***Open Specs & Standards***
- ***Long-Term Relationships***

IMPLEMENTATION DRIVERS

should be able to participate in both commercial and defense markets. Ideally, Navy R&D results would be shared as much as possible among same-tier activities.

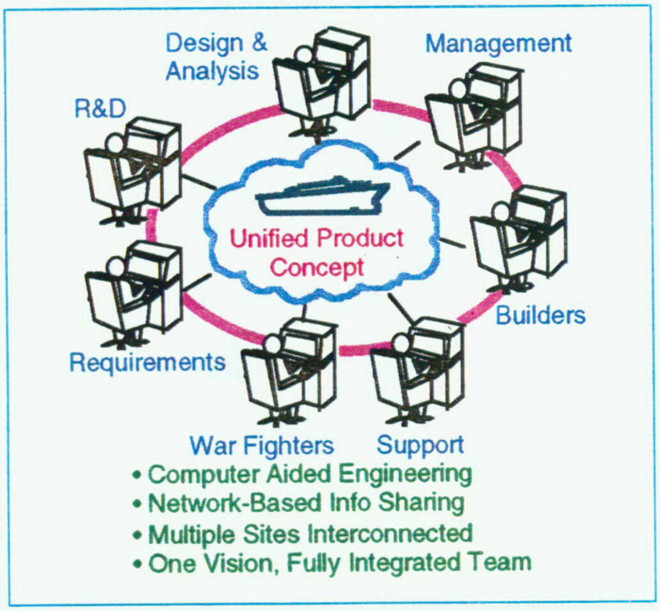
Teamwork Environment

Teamwork is one of the key characteristics sought in the target total ship engineering process. This calls for use of a systems-of-systems engineering approach and reliance on shared concepts, standards, and tools to promote design integration. The first and most important step is probably to form a cadre able to consider trade-offs from a total ship perspective. At the same time, full appreciation for (and access to) the specialized technical knowledge of functional activities remains essential. Teamwork is very difficult because the problem is very complex. By fostering a shared understanding of the problem and adopting a common language, cadres can learn to work effectively together from different locations, as long as frequent communication is permitted.



COLLOCATED TEAM

The idea of using computer networks for teamwork is no longer a new one. Today it is possible to think of a team being brought together on the network, sharing information and holding meetings entirely via the network, using common design aids and groupware. A virtual team is an integrated product team consisting of members with different perspectives on product development, wielding powerful computer-aided engineering (CAE) tools in their individual work spaces but publishing results to a shared information base. An overarching coordination service may also exist to schedule work, report progress, notify persons, authorize work, and carry out entire suites of coordinated processes without the need for face-to-face meetings.



VIRTUAL TEAM APPROACH

The next section considers what opportunities exist currently for pursuing the broad actions identified in this section. It is essential to recognize that ship development tends to be evolutionary in character. Ships are so complex that it is difficult to create entirely new combatants with no use of legacy systems.

VISION AND OPPORTUNITIES

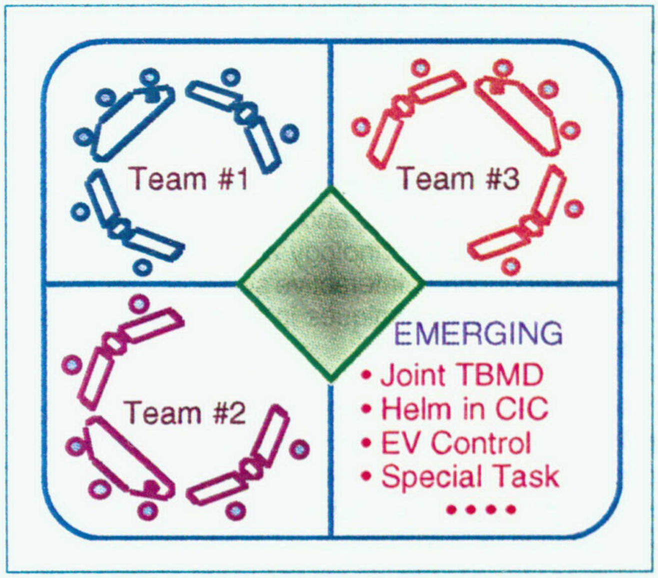
Begin With Mission Teams

As indicated earlier, mission teams and tasks are the starting point for the total ship system engineering process. A key goal for process improvement is to strengthen the sense of partnership between mission teams and the development and support teams that exist to provide them with resources. Primary emphasis here is on understanding what the mission teams must do and engineering systems to support or execute those tasks efficiently. Future ships will fight by wire! The control backbones interface the warfighter with the weapons, sensors, and other resources used to carry out the mission. The backbones determine not only the "look and feel" of the ship to the warfighter but have embedded in them how the ship will be fought in terms of processes and procedures. It is thus imperative to have the warfighter involved in the design process. Designers must listen to the "voice of the warfighter," the customer.

Vision For Command Spaces

Littoral warfare operations seem likely to demand increased flexibility in surface ship command and control capabilities. For example, a future combatant might be organized to deal with power projection, battle space dominance, information warfare, survivability, and mobility as the major operational tasks to be performed. In addition, various special-purpose teams, such as a joint air identification team or a Marine Corps air defense control team, might have to be supported. It could also be necessary to adapt to changes in the joint command structure as a conflict situation evolves. Indeed, each forward deployment cycle might call for a different command structure, or variation from some core structure. Reconfigurable and flexible command spaces are then important, permitting adaptation to specific mission needs through rearrangement of mission teams and watch stations. System engineering methods must be formulated to identify designs that are open and adaptable to emerging needs and to provide decision aids for tailoring a ship's command structure to specific mission needs.

Future command spaces should be designed as open systems to enable easy upgrades as well as operational flexibility. The initial design should be viewed as the nucleus of a more advanced or larger



ADAPTABLE COMMAND SPACES

system, with hooks installed to support change. As indicated in the box below, a wide range of new systems and technologies are likely to appear in command spaces over the next few decades. In time, major changes are likely in how military forces organize to use information. This could mean collaborative work styles instead of hierarchies, in which bottlenecking limits flexibility. Future systems may use network structures extending across the life lines. Another key source of change is automation, which can alter task allocation between humans and machines. To prepare the way for change, it is important to establish a disciplined process for managing life cycle cost and system integrity.

APPLICATIONS
- Distributed Command Systems
- Wide Area Surveillance Displays
- Integrated Command Support
- Novel Layout (e.g., Sensurround)

TECHNOLOGIES
- Teleconference Capability
- Interactive and 3D Displays
- Virtual Reality in Planning
- Enhanced Operator Interfaces
- Automation to Reduce Manning

TRENDS IN COMMAND SPACES

Technology Opportunities

Future watch stations will provide better displays, new ways for people to interact with computers, and better ways to aid decision making. Opportunities include the following.

- *Human – Computer Interfaces.* How operators interact with displays can be much better than today's hook, ball tab, and cursor technique. Interactive device technology will permit the use of voice recognition, interactive screens, and a variety of pointing techniques in future display interfaces.

Pointing techniques will include eye-safe laser devices, photoelectric light-sensitive pointing devices, mouse pads, and other devices. There are existing prototypes that allow interaction with various displays via eye contact. This has been done to let pilots get information without use of any other device. Interactive (touch-sensitive) screens exist today and improvements in granularity and sensitivity will continue.

- *Graphics.* Future displays will use new techniques to aid tactical operators. New symbol sets will permit use of icons in tactical displays, leading to reduced training time and better retention of skills.

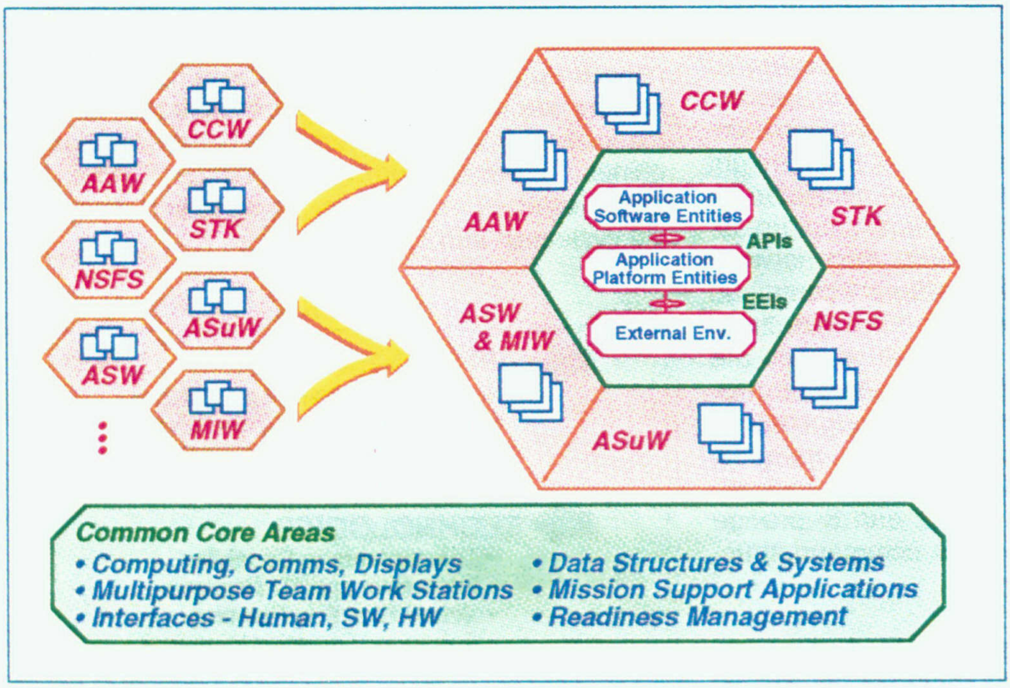
Extensive use will be made of color, windows, icons and new display heads. The latter may include large wall screen, tabletop, or 3D displays. Volumetric (3D) displays promise to immerse decision makers in the tactical scene, where they can better use the cognitive skills underlying human vision to grasp and utilize available information.

- *Enhanced Communications.* This will include the use of hand-held, wireless, intraship communications supported by an automated locator service.

Common Backbone For Combat Systems

Based on the total ship system engineering process and partitioning scheme outlined in preceding sections, reengineering opportunities have been addressed for the combat control area. The main question considered in this pilot study was whether it makes sense to talk about a common system engineering framework across many different projects in the combat system category. Results indicate a common backbone structure may be feasible in future combat systems. The figure below illustrates the concept. This would mean, for the combat system as a whole, the kind of flexibility and resource sharing achieved by the Vertical Launching System in handling multiple missile types or by the AEGIS Weapon System in handling multiple simultaneous targets.

The idea of a common operating environment (COE) is usually applied only to a computing environment. Creating a common backbone for combat control means a COE defined more broadly, to include not only processing resources but also displays, watch stations, interfaces, communications, and mission support applications.



COMBAT CONTROL BACKBONE

mon system services will be provided to deal with configuration management functions, such as naming or maintaining a common data element dictionary. The backbone would provide a standards-based framework for development and integration of individual combat systems. Individual system programs would adopt a narrower focus on delivery of mission-unique applications and components. Use of an open system framework can make a common backbone approach both affordable and capable. The potential benefits appear very significant.

MODULAR FRAMEWORK

Vision For Ship Integration

The advantages of a common backbone apply to all areas as shown in the figure. What is envisioned is a generic backbone (with variants for each area) that supports design for modularity, commonality, and the sharing of functional resources on a shipwide basis. This modular framework must have the following attributes:

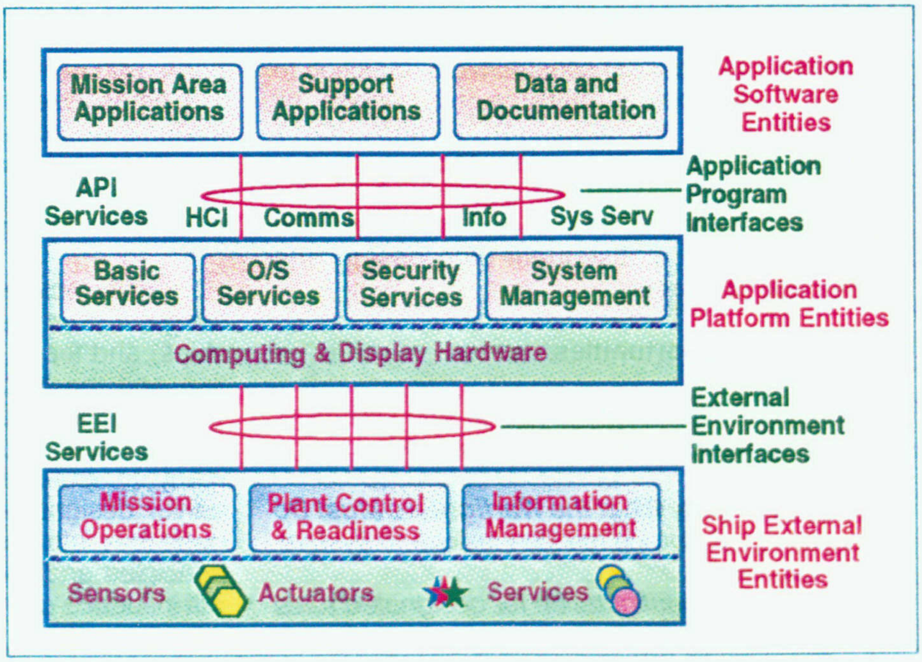
- *Command spaces become utilities, tailorable to any set of mission teams and tasks required.*
- *Computing, communication, and display resources are managed on a shipwide basis, with a common application environment maintained.*
- *Readiness and resources are managed on a shipwide basis.*
- *Life cycle costs are reduced by holding manning and parts counts to minimum levels, and by an open systems approach.*

Overall, the resulting architecture is intended to be enduring, flexible to permit (a) application to a variety of ship types and designs; (b) insertion of new functionality as warfighting systems evolve; and (c) insertion of new technology as it becomes available. The original architecture should include an extension framework and be subject to formal change control from the earliest stages of development.

Total Ship Target Architecture: A Common Operating Environment

The figure below represents the ship as a layered open system with three entity types and two interface types. The target architecture represents a strategy for applying the concept of open systems to warship development. The qualities of portability and interoperability offered by open systems are combined with the reliability and effectiveness needed in combatants.

The target architecture is layered to form two loosely coupled subsystems. The first links application software entities to application platform entities. As in the Application Portability Profile defined by NIST (Reference 6), the basic idea is to make the services provided by the application platforms (at their interfaces) transparent to application



TOTAL SHIP TARGET ARCHITECTURE

ware. This first subsystem is then loosely coupled, in that application platform entities become interchangeable and application software entities become reusable.

The second subsystem links external environment entities to application platform entities. Again, the basic idea is to make services provided by the latter (at their interfaces) transparent to individual sensors, weapons, work stations, machinery, and service systems throughout the ship. Both application platform entities and external environment entities are viewed as providers of standard services, and any two elements providing equivalent services should be interchangeable.

An Evolutionary Strategy

The idea of a common backbone system is promising, but much remains to be done. One of the hard spots concerns the lack of a working baseline with open system characteristics. While reliable and effective, combat systems today are hardly open, and it is not yet clear how to deal with the problems of weapon safety certification for open systems.

Migrating to an open system involves an extra measure of risk that is important for both program executives and suppliers. Creating incentives for taking the associated risks is therefore an important goal. A related problem is to find ways to effectively manage standards-based backbone architectures, as standards evolve with time.

Given today's budget constraints, a transition to common backbones probably won't happen all at once. However, the existing SC 21 and LPD-17 programs offer a starting point. Progress made toward a common backbone structure in these programs could be the foundation for full implementation in subsequent ship design and construction programs.

Summary of Opportunities

The attributes sought in a total ship system engineering process can be listed as follows:

Process Driven by What the Warfighters Must Do
- *Continuous dialog on mission tasks and system characteristics*
- *Ability to tailor configuration for designated roles and operational areas*

Common Backbones and Building Blocks
- *Same control backbones applicable to all ship types*
- *Command spaces become utilities, useful for any mission task*
- *Plug and play flexibility of mission systems, data, resource flows*

Open Systems
- *Portable, scalable, reconfigurable, interoperable, extensible*
- *Easy upgrades for better performance, reliability, and flexibility*
- *Extensive use of commercial products*

Exploit Potential for Improved Design Methods
- *Simulation-based design capabilities*
- *Reengineered mission teams and operating processes*

A good deal of attention was given to selection of the proper starting point. In the final analysis, we believe that the purpose of ships is to carry mission teams to a chosen operating area (at sea). What ships must do depends on the designated mission teams and tasks. System engineers must work constantly with the warfighters to define the necessary mission teams and tasks, and to engineer the operating processes necessary to carry out those tasks.

The advantages of a common backbone apply not only to combat control, but to plant control and readiness, and to the area of information management as well. What is envisioned is a generic backbone (with variants for each area) applicable across ship types. Use of common building blocks and open systems would be emphasized on a shipwide basis for all categories of systems (e.g., pumps, electrical systems) and not just control structure. Ships would thus have a minimum set of piece parts.

Finally, new engineering methods and tools offer great promise for improving the product (warships) and the process of warship design, acquisition, and construction. Opportunities in this area are especially important because in a sense warship design never starts with a blank sheet of paper: many components used in construction are built to earlier designs, and modernization during the life cycle may introduce still later designs. Engineering principles and methods embedded in design aids will influence compatibility of designs from different decades.

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